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Radiocommunication Sector of ITU

Recommendation ITU-R M.2010-1
(01/2019)

Characteristics of a digital system, named Navigational Data for broadcasting maritime safety and security related information from shore-to-ship in the 500 kHz band

M Series

Mobile, radiodetermination, amateur and related satellite services

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Note*: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
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RECOMMENDATION ITU-R M.2010-1

Characteristics of a digital system, named Navigational Data for broadcasting maritime safety and security related information from shore-to-ship in the 500 kHz band

(2012-2019)

Scope

The Recommendation describes an MF radio system, named navigational data (NAVDAT), for use in the maritime mobile service, operating in the 500 kHz band for digital broadcasting of maritime safety and security related information from shore-to-ship. The operational characteristics and system architecture of this radio system are included in Annexes 1 and 2. Technical characteristics and transmission structure are detailed in Annexes 3 and 4. Message file structure and a broadcast mode are introduced in Annexes 5 and 6.

Keywords

500 kHz, broadcasting, NAVDAT

Abbreviations/Glossary

CDU	Control and display unit
CRC	Cyclic redundancy check
DRM	Digital radio mondiale
DS	Data stream
GF	Galois Field or finite field
GNSS	Global navigation satellite system
IMO	International maritime organization
LDPC	Low density parity-check
MER	Modulation error rate
MIS	Modulation information stream
NAVDAT	Navigational data (the system name)
NAVTEX	Navigational telex (the system name)
OFDM	Orthogonal frequency division multiplexing
PRBS	Pseudo-random binary sequence
QAM	Quadrature amplitude modulation
RS	Reed-solomon codes
SFN	Single frequency network
SIM	System of information and management
TIS	Transmitter information stream

Related ITU Recommendations, Reports

Recommendation ITU-R BS.1514 – System for digital sound broadcasting in the broadcasting bands below 30 MHz

Recommendation ITU-R M.493 – Digital selective-calling system for use in the maritime mobile service

Recommendation ITU-R M.585 – Assignment and use of identities in the maritime mobile service

Recommendation ITU-R P.368 – Ground-wave propagation curves for frequencies between 10 kHz and 30 MHz

Recommendation ITU-R P.372 – Radio noise

Report ITU-R M.2201 – Utilization of the 495-505 kHz band by the maritime mobile service for the digital broadcasting of safety and security related information from shore-to-ships

The ITU Radiocommunication Assembly,

considering

a) that high speed data broadcast from shore-to-ships enhances operational efficiency and maritime safety;

b) that the navigational telex NAVTEX system has limited capacity;

c) that the e-Navigation system of the International Maritime Organization (IMO) increases the demand for data transmission from shore-to-ship;

d) that the 500 kHz band provides good coverage for digital systems,

recognizing

that the Digital Radio Mondiale (DRM) system referenced in Annex 6 has been incorporated in Recommendation ITU-R BS.1514,

noting

that Report ITU-R M.2201 provides the basis for the NAVDAT system,

recommends

1 that the operational characteristics for the broadcasting of maritime safety and security related information should be in accordance with Annex 1;

2 that the system architecture of the broadcasting system for maritime safety and security related information should be in accordance with Annex 2;

3 that the technical characteristics and modem protocols for digital data transmission from shore-to-ships in the 500 kHz band should be in accordance with Annexes 3 and 4;

4 that the data stream of the system and the message structure should be in accordance with Annex 5.

Annex 1

Operational characteristics

The NAVDAT system uses a time-slot allocation similar to the NAVTEX system which could be coordinated by IMO in the same manner.

That NAVDAT system can also work on a single frequency network (SFN) as described in Annex 6. In this case transmitters are frequency synchronized and the transmit data must be the same for all transmitter.

The NAVDAT 500 kHz digital system offers a broadcast transmission of any kind of message from shore-to-ships with possibility of encryption.

1 Type of messages and files

Any broadcasting message should be provided by a secure and controlled source.

Message types broadcast can include, but are not limited to, the following:

– safety of navigation;

– security;

– piracy;

– search and rescue;

– meteorological messages;

– piloting or harbour messages;

– vessel traffic system files transfer;

– electronic chart update packages.

2 Broadcast modes

2.1 General broadcast

These messages are broadcasted for the attention of all ships.

2.2 Selective broadcast

These messages are broadcasted for the attention of a group of ships[1] or in a specific navigation area[2].

2.3 Dedicated message

These messages are addressed to one ship, using the maritime mobile service identity.

3 Broadcast priority

NAVDAT is capable to broadcast messages with distress, urgency, safety in the order defined by IMO International SafetyNET Manual.

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[1] The group call identification format of the ship station is defined in part 1 of Annex 1 of Recommendation ITU-R M.585.

[2] The definition of geographical coordinates is referred to 5.3 in Annex 1 of Recommendation ITU-R M.493.

Annex 2

System architecture

1 The broadcast chain

The NAVDAT system is organized upon five vectors performing the following functions:

– System of information and management (SIM):
  - collects and controls all kinds of information;
  - creates message files to be transmitted;
  - creates transmitting programme according to message files priority and need of repetition;
  - monitors the operating status and broadcast quality of the shore transmitter;
  - controls the operating parameters of shore transmitter.

– Shore network:
  - assures the transportation of the message files and monitor data from sources to the transmitters.

– Shore transmitter:
  - receives the message files from SIM;
  - translates message files to orthogonal frequency division multiplexing (OFDM) signal;
  - transmits RF signal to the antenna for broadcast to ships;
  - monitors operating status and reports to the SIM.

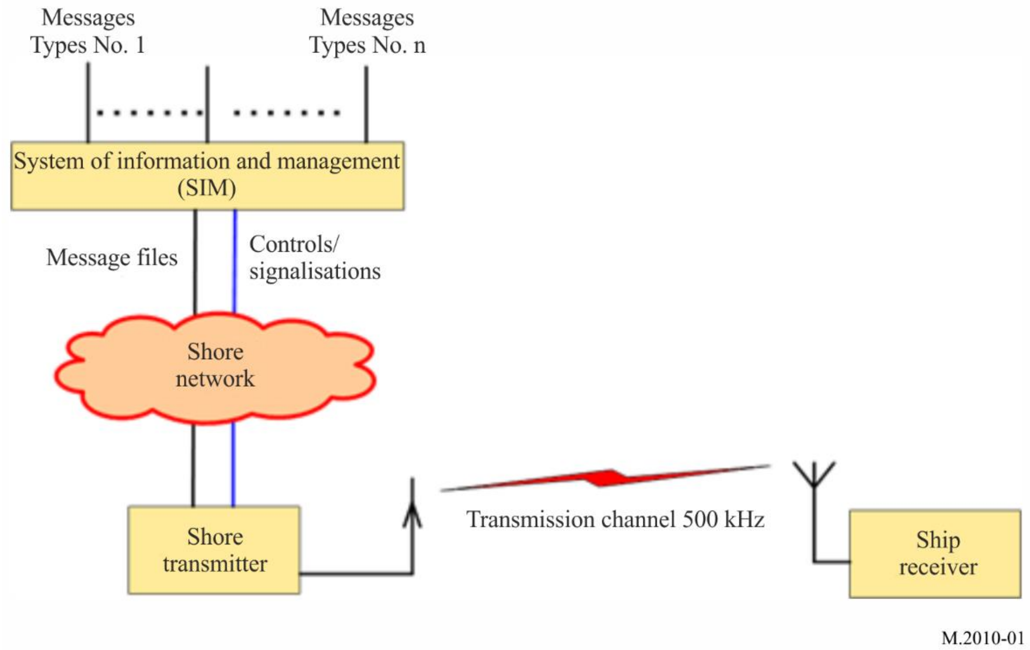
– Transmission channel:
  - Transports the 500 kHz RF signal.

– Ship receiver:
  - demodulates the RF OFDM signal;
  - reconstructs the message files;
  - sorts and makes the message files available for the dedicated equipment according to the message files applications, or displays the contents of the message files.

Figure 1 shows the diagram of the broadcast chain.

FIGURE 1

NAVDAT 500 kHz broadcast chain block diagram



1.1 System of information and management

The SIM term includes:

– all the sources that deliver file messages (e.g. meteorological office, safety and security organizations, etc.);

– the file multiplexer which is an application running on a server;

– the file multiplexer manager;

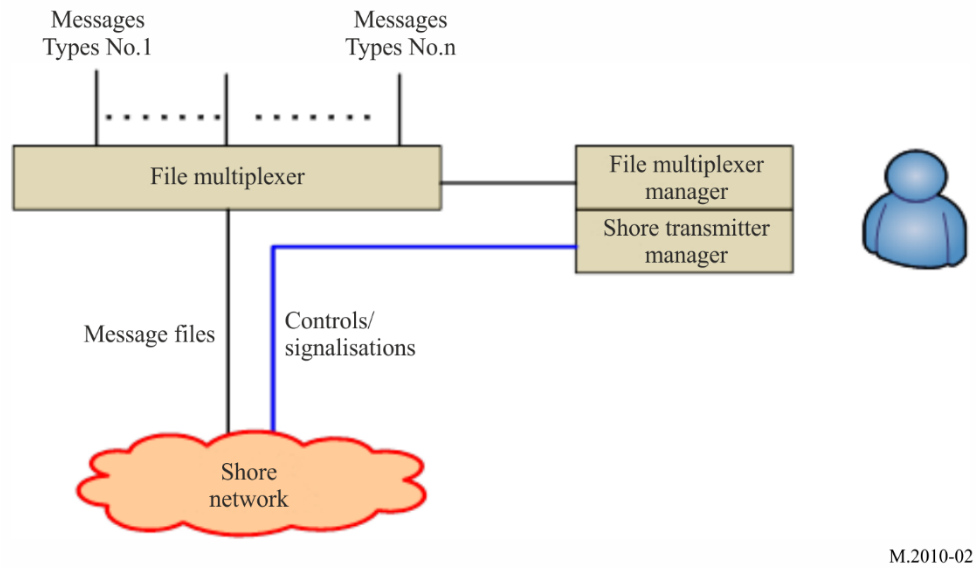
– the shore transmitter manager.

All the sources are connected to the file multiplexer through a network.

Figure 2 shows the general diagram of the SIM.

FIGURE 2

NAVDAT system of information and management block diagram



1.1.1 File multiplexer

The file multiplexer:

– takes delivery of the message files from the data sources;

– encrypts the message files if asked;

– formats the file messages with recipient information, priority status and time validity;

– sends the message files to the transmitter.

1.1.2 File multiplexer manager

The file multiplexer manager is a man machine interface that enables the user to, among other tasks:

– have a look at the message files coming from any source;

– specify the priority and periodicity of the any message file;

– specify the recipient of any message file;

– manage the file message encryption.

Some of these functionalities may be automated. As an example, the priority and the periodicity of a message may be selected according to the source it comes from or the source may specify the priority in the message.

1.1.3 Shore transmitter manager

The shore station manager is a man machine interface connected to the transmitter through the network; it makes it possible to supervise the transmitter status indications such as:

– transmit acknowledgment;

– alarms;

– effective transmit power;

– synchronization report;

– quality of transmission;

and to change the transmitter parameters, such as:

– transmit power;

– OFDM parameters (pilot subcarriers, modulation, error coding, etc.);
– transmission schedule.

1.2 Shore network

The shore network can use a broadband link, a low data rate link or a local file sharing.

1.3 Shore transmitter description

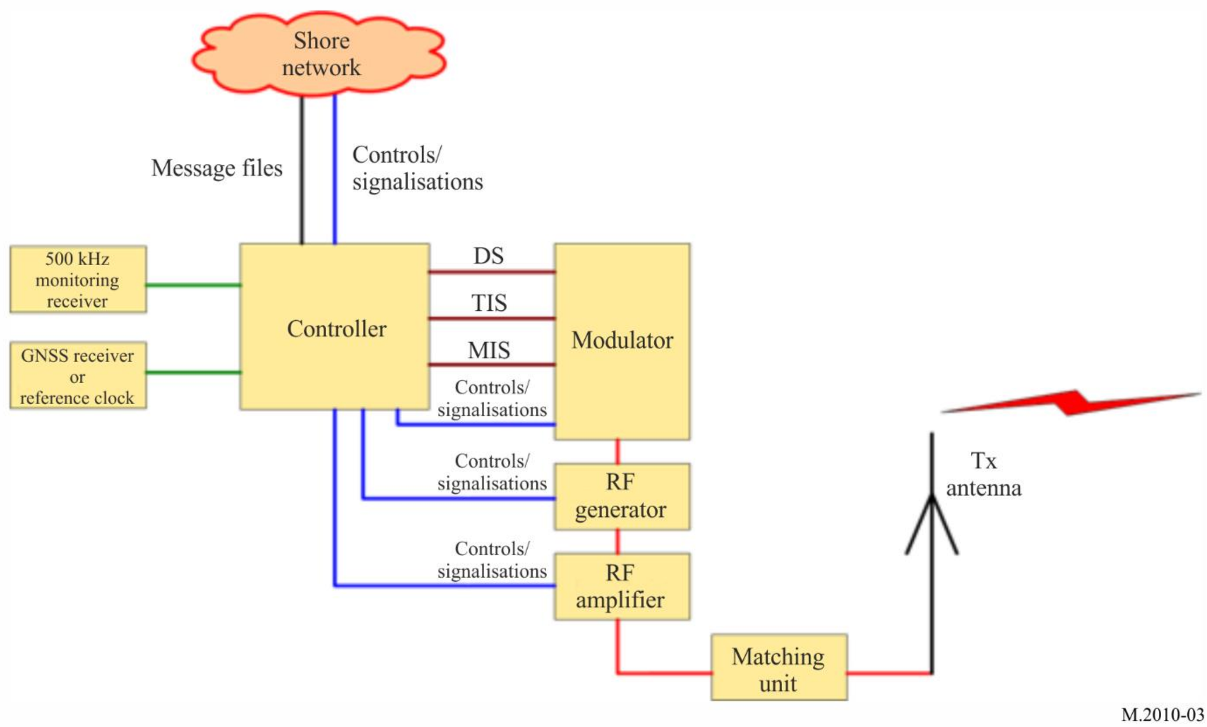
A coastal transmitting station consists of this minimum configuration:
– controller, which is a local server with access protection;
– OFDM modulator;
– RF generator;
– RF power amplifier;
– transmit antenna with matching unit;
– global navigation satellite system (GNSS) receiver or atomic clock for synchronization;
– monitoring receiver with its antenna.

1.3.1 Shore system architecture

Figure 3 shows the block diagram of a 500 kHz digital transmitter.

FIGURE 3

NAVDAT 500 kHz transmitter functional block diagram



1.3.2 Controller

This unit receives some pieces of information:
– message files from SIM;
– GNSS or reference clock for synchronization;

– 500 kHz signal from monitoring receiver;
– Modulator, 500 kHz signal RF generator, RF power amplifier control signals and monitoring.

The function of the controller is:

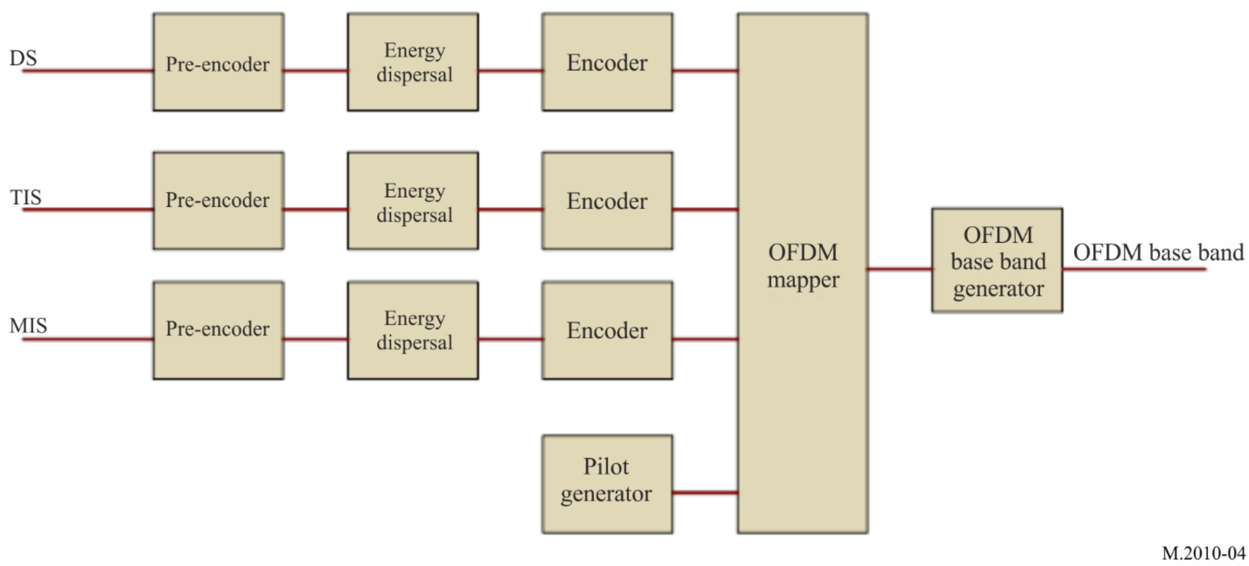
– to check if the frequency band 495-505 kHz is free before transmission;
– to synchronize all signals on the coast station from synchronization clock;
– to control the transmission parameters, time and schedule;
– to format the message files to be transmitted (split files into packets).

1.3.3 Modulator

Figure 4 shows the diagram of the modulator.

FIGURE 4

NAVDAT 500 kHz modulator functional block diagram



1.3.3.1 Input streams

In order to operate, the modulator needs three input streams:

– modulation information stream (MIS);
– transmitter information stream (TIS);
– data stream (DS).

These streams are transcoded and then placed on the OFDM signal by the cell mapper.

1.3.3.1.1 Modulation information stream

This stream is used to provide information about:

– the spectrum occupancy;
– the modulation for transmission information stream and data stream (4, 16 or 64-QAM).

This MIS stream is always coded on 4-QAM subcarriers for good demodulation into the receiver.

1.3.3.1.2 Transmitter information stream

This stream is used to provide information to the receiver about:

– error coding for data stream (should be different for surface wave propagation at day time and for surface + sky wave propagation at night time);

– identifier of the transmitter;

– date and time.

This TIS stream can be coded on 4 or 16-QAM.

1.3.3.1.3 Data stream

It contains the message files to transmit (these message files were previously formatted by the file multiplexer).

1.3.3.2 Error encoding

The error correction scheme determines the robustness of the coding. The code rate is the ratio between useful and raw data rate. It illustrates the transmission efficiency and can vary between 0.5 and 0.75 depending on the error correction schemes and modulation patterns.

1.3.3.3 Orthogonal frequency division multiplexing generation

The three streams (MIS, TIS and DS) are formatted:

– encoding;

– energy dispersal.

A cell mapper organizes the OFDM cells with the formatted streams and the pilot cells. The pilot cells are transmitted for the receiver to estimate the radio channel and synchronize on the RF signal.

An OFDM signal generator creates the OFDM base band according to the output of the cell mapper.

1.3.4 500 kHz RF generator

A 500 kHz RF generator transposes the base band signal to 500 kHz RF output carrier.

An amplifier brings the RF signal to the desired power.

1.3.5 RF amplifier

The function of this stage is to amplify the 500 kHz signal from the generator output to the necessary level to obtain the desired radio coverage.

The OFDM transmission introduces a crest factor on the RF signal. This crest factor must stay in the range 7 to 10 dB at the RF amplifier output for a correct modulation error rate (MER).

1.3.6 Transmit antenna with matching unit

The RF amplifier is connected to the transmit antenna through the impedance matching unit.

1.3.7 Global navigation satellite receiver and a backup atomic reference clock

The clock is used to synchronize the local controller and configure a high-precision reference clock when working in SFN mode.

1.3.8 Monitoring receiver

The monitoring receiver checks that the frequency band 495-505 kHz is free before transmission and offers possibility to check the transmission. A remote monitoring receiver is recommended for monitoring the local signal reception quality.

1.4 Transmission channel: Radio coverage estimation

The coverage could be calculated based on the most recent version of Recommendations ITU-R P.368 and ITU-R P.372. See Report ITU-R M.2201for an example.

Annex 3

NAVDAT technical characteristics

1 Modulation principle

The system uses OFDM which is a modulation technology for digital transmissions.

1.1 Introduction

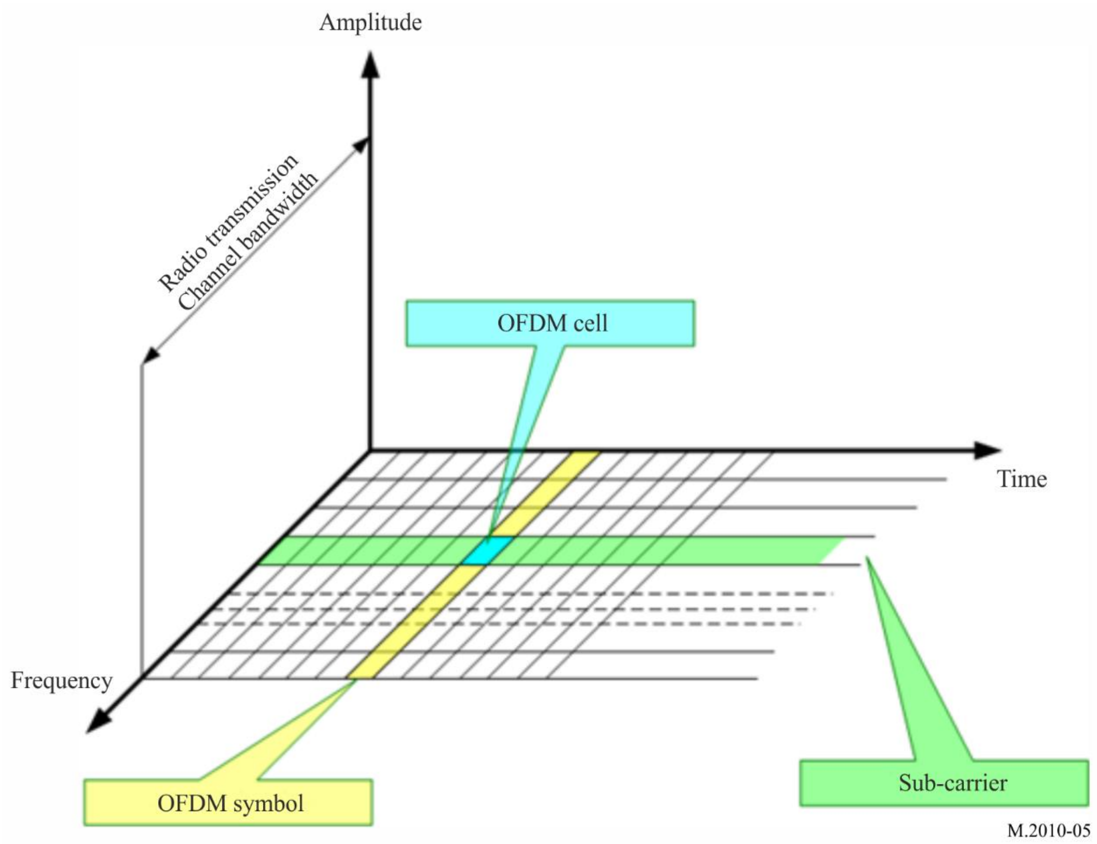
The bandwidth of the radio transmission channel is divided in the frequency domain to form subcarriers.

The radio transmission channel occupancy is organized in the time to form OFDM symbols.

An OFDM cell is equivalent to one subcarrier in one OFDM symbol.

FIGURE 5

OFDM plexing introduction



1.2 Principle

The OFDM uses a large number of closely-spaced (41.66 Hz) orthogonal subcarriers to obtain high spectral efficiency to transmit data. These subcarriers are frequency-spaced (Fu = 1/Tu), where T_U is the OFDM symbol duration.

The phases of subcarriers are orthogonal one to each other to enhance signal diversity caused by the multipath, especially in long distance.

A guard interval (Td) is inserted in the OFDM symbol to reduce multipath effect, thus reducing the inter-symbol interference.

The OFDM symbol duration is Ts = Tu + Td

The OFDM symbols are then concatenated to make an OFDM frame.

The OFDM frame duration is Tf.

FIGURE 6

Spectral representation of an OFDM frame

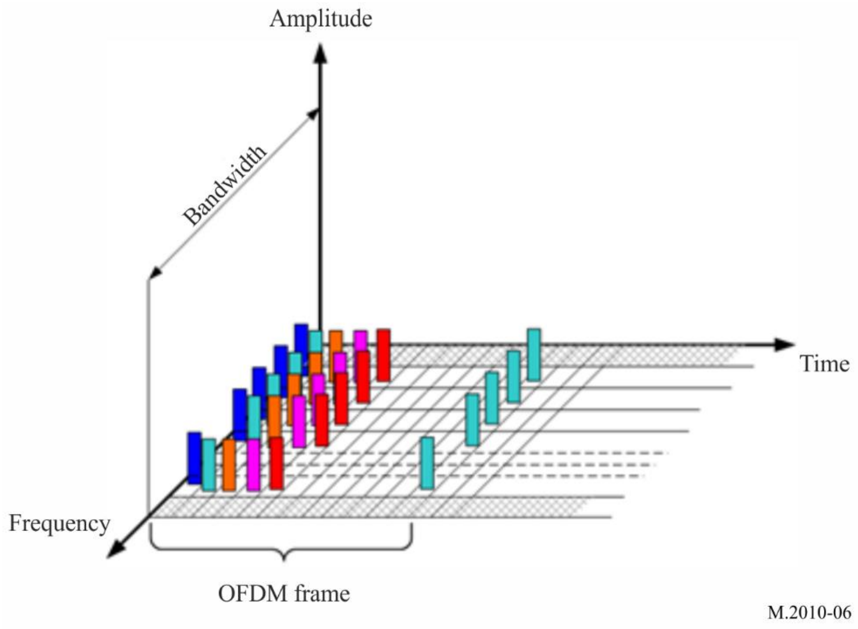
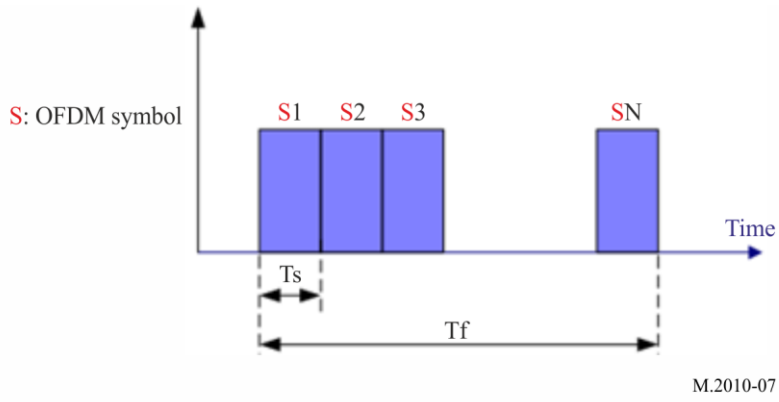


FIGURE 7

Temporal representation of an OFDM frame



1.3 Orthogonal frequency division multiplexing parameters

OFDM parameter values are listed in Table 1.

TABLE 1

Orthogonal frequency division multiplexing parameter values

T_u	$1/T_u$	T_d	T_s=T_u+T_d	N_s	T_f
24 ms	$41^{2/3}$ Hz	2.66 ms	26.66 ms	15	400 ms

T_u: duration of the useful part of an OFDM symbol

$1/T_u$: carrier spacing

T_d: duration of the guard interval

T_s: duration of an OFDM symbol

N_s: the number of symbols per frame

T_f: duration of the transmission frame.

1.4 Channel bandwidth

NAVDAT digital broadcast defines different channel bandwidths and determines subcarrier numbers corresponding to different spectrum occupancy rates. Table 2 presents the channel bandwidth value and subcarrier numbers.

TABLE 2

Relationship between channel bandwidth and orthogonal frequency division multiplexing sub-carrier numbers

	Spectrum occupancy			
	1	**2**	**3**	**4**
Channel bandwidth (kHz)	1	3	5	10
Number of subcarriers	23	69	115	229
Subcarrier number k	k = −11 to 11	k = −34 to 34	k = −57 to 57	k = −114 to 114

1.5 Modulation

Every subcarrier is modulated in amplitude and phase (QAM: Quadrature amplitude modulation).

Modulation patterns can be either 64 states (6 bits, 64-QAM), 16 states (4 bits, 16-QAM), or 4 states (2 bits, 4-QAM).

The modulation pattern depends on the desired robustness of the signal.

FIGURE 8

4-QAM constellation

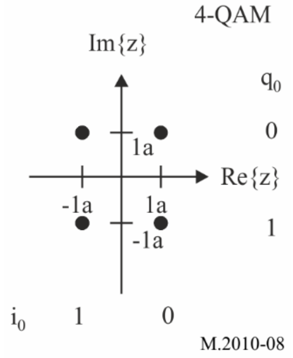


FIGURE 9

16-QAM constellation

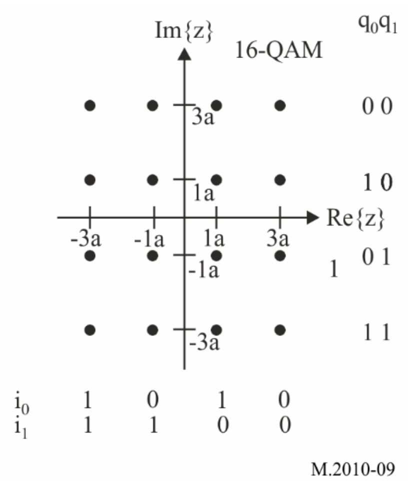
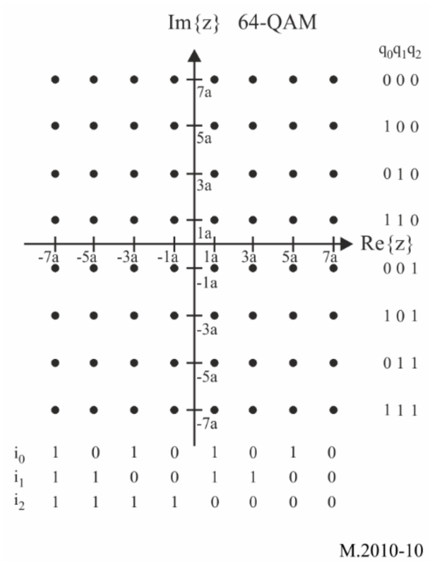


FIGURE 10

64-QAM constellation



1.6 Synchronization

In order to allow a good demodulation of each subcarrier, the radio transmission channel response must be determined for each subcarrier and the equalization should be applied. For this, some of the subcarriers of the OFDM symbols may carry pilot signals.

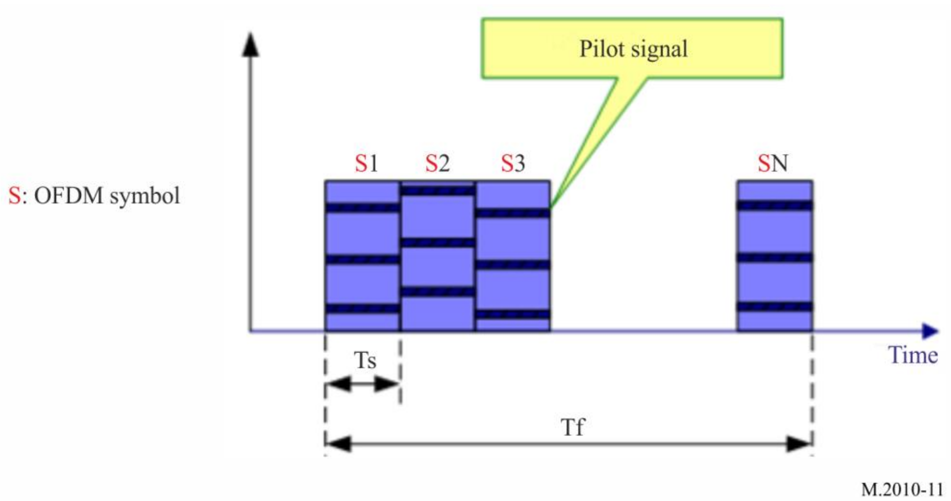
The pilot signals allow the receiver to:

– detect if a signal is received;
– estimate the frequency offset;
– estimate the radio transmission channel.

The number of pilot signals depends on the desired robustness of the signal.

FIGURE 11

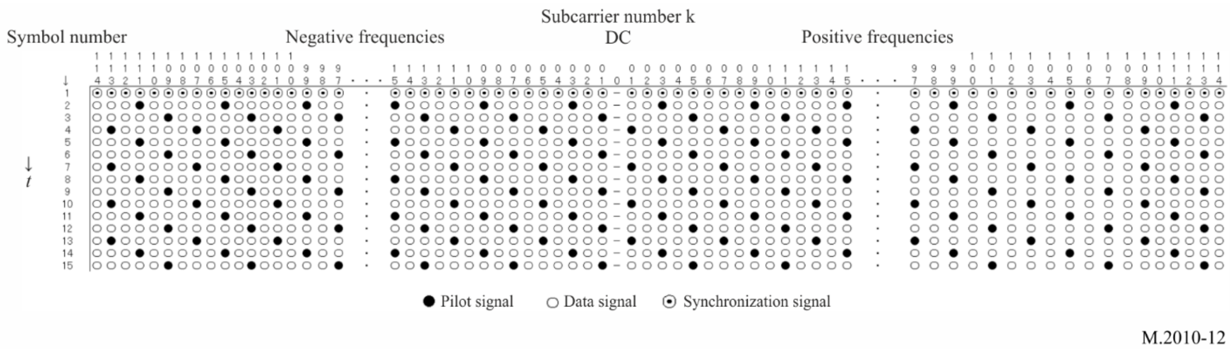
Pilot OFDM signal



The pilot signal location in each OFDM symbol in a frame can be shown as follows:

FIGURE 12

The pilot signal location



Where t is the direction of time domain, f is the direction of frequency domain. The first symbol of each OFDM frame shall be filled by a sequence of synchronization signals that make up the synchronization head (refer to Table 7), all of which are used as a time reference to provide synchronization for the receiver. The black cell and the white cell represent the pilot signal and the data signal, respectively. The pilot signal value which is modulated in 2-QAM (BPSK) in an OFDM symbol is shown in Table 3.

TABLE 3

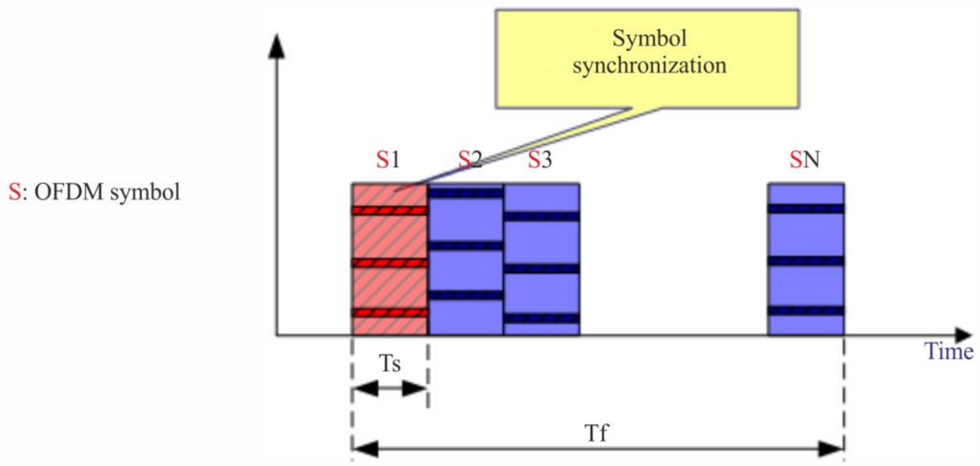
Pilot sequence

Number of subcarriers	Pilot sequence
229	-1 1 -1 1 -1 1 1 1 -1 1 1 1 1 -1 -1 -1 1 1 -1 -1 -1 1 1
115	-1 1 -1 1 -1 1 1 1 -1 1 1 1
69	-1 1 -1 1 -1 1 1
23	-1 1 -1

In the first symbol of each OFDM frame, any subcarriers are used as time reference for the receiver to synchronize.

FIGURE 13

Synchronization symbol



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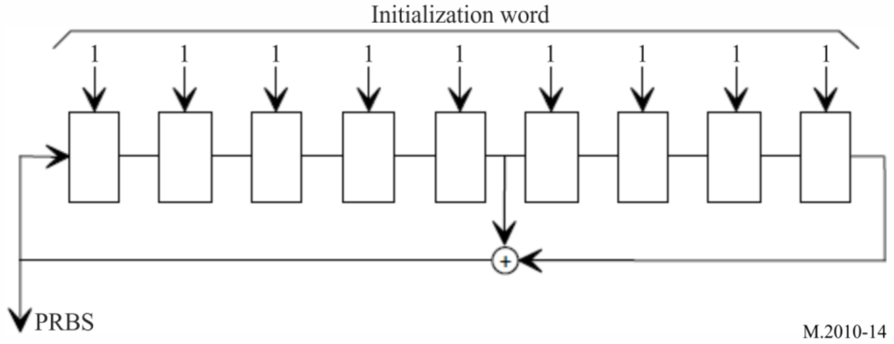
1.7 Energy dispersal

The purpose of the energy dispersal is to avoid the transmission of signal patterns resulted in an unwanted regularity. The individual inputs of energy dispersal scramblers should be scrambled by a modulo-2 with a pseudo-random binary sequence (PRBS), prior to channel encoding. The PRBS is defined as the output of the feedback shift register of Fig. 14. It should use a polynomial of degree 9, defined by:

$$P(X)=X^9+X^5+1$$

FIGURE 14

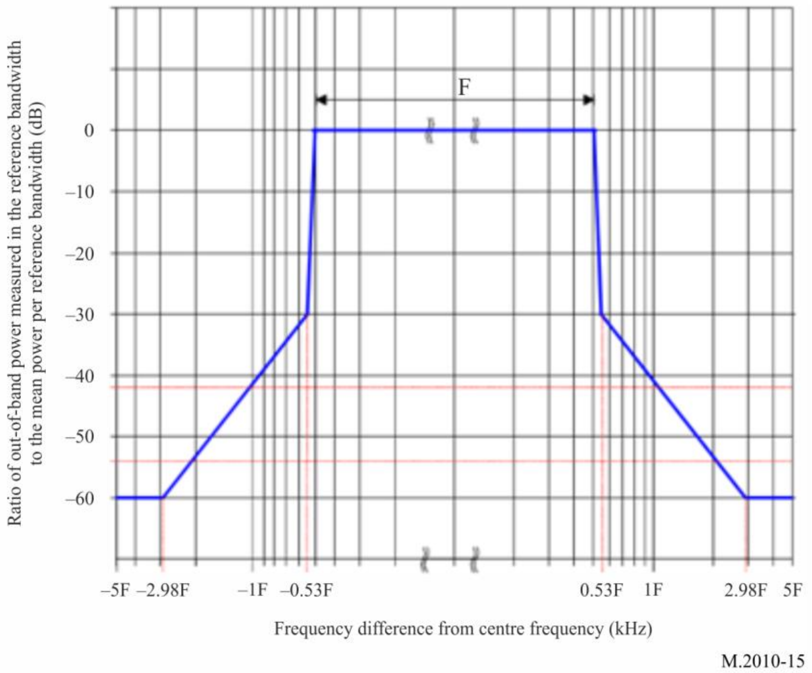
Pseudo-random binary sequence generator



1.8 Spectral occupancy of RF signal

FIGURE 15

Spectral occupation of NAVDAT RF signal with bandwidth F = 10 kHz



2 Estimated usable data rate

In the 10 kHz channel bandwidth with 500 kHz propagation, the raw data rate available for the DS is typically around 25 kbit/s with 16-QAM signal.

The number of subcarriers that hold data can be varied in order to adjust the channel protection. Higher channel protection (protection against multipath, fading, delay, etc.) results in a lower number of useful subcarriers.

Error coding must then be applied to the raw data rate to obtain the useful data rate. With a code rate of 0.5 to 0.75, the useful data rate is then between 12 and 19 kbit/s.

A higher code rate provides a higher useful data rate but the radio coverage is accordingly reduced.

With the different modulation and code rate, the useful data rate is shown as below.

TABLE 4

Data rate

Mode	Modulation (nQAM)	Code rate	Estimated data rate (kbps)
0	4-QAM	0.5	6.36
1	4-QAM	0.75	9.56
2	16-QAM	0.5	12.76
3	16-QAM	0.75	19.16
4	64-QAM	0.5	19.16
5	64-QAM	0.75	28.76

3 NAVDAT transmitter performance specification

TABLE 5

Minimum NAVDAT transmitter performance specification

Parameters	Required results
Frequency band	495 to 505 kHz
Carrier frequency error	Within ±2.5 Hz of the nominal frequency
Spectrum mask	Comply with the requirements of Figure 15
Transmitter third-order intermodulation rejection ratio	≥40 dBc
Transmitter emission spurious (all power range)	−50 dB without exceeding the absolute level of 50 mW (17 dBm)

4 NAVDAT ship receiver

4.1 NAVDAT ship receiver description

The ship receiver block diagram is shown in Fig. 16.

A typical NAVDAT 500 kHz digital receiver is composed of several basic blocks:

– MF reception antenna and optional GNSS antenna;

– RF front end;

– demodulator;

– file demultiplexer;

– controller;

– Control and display unit (CDU);

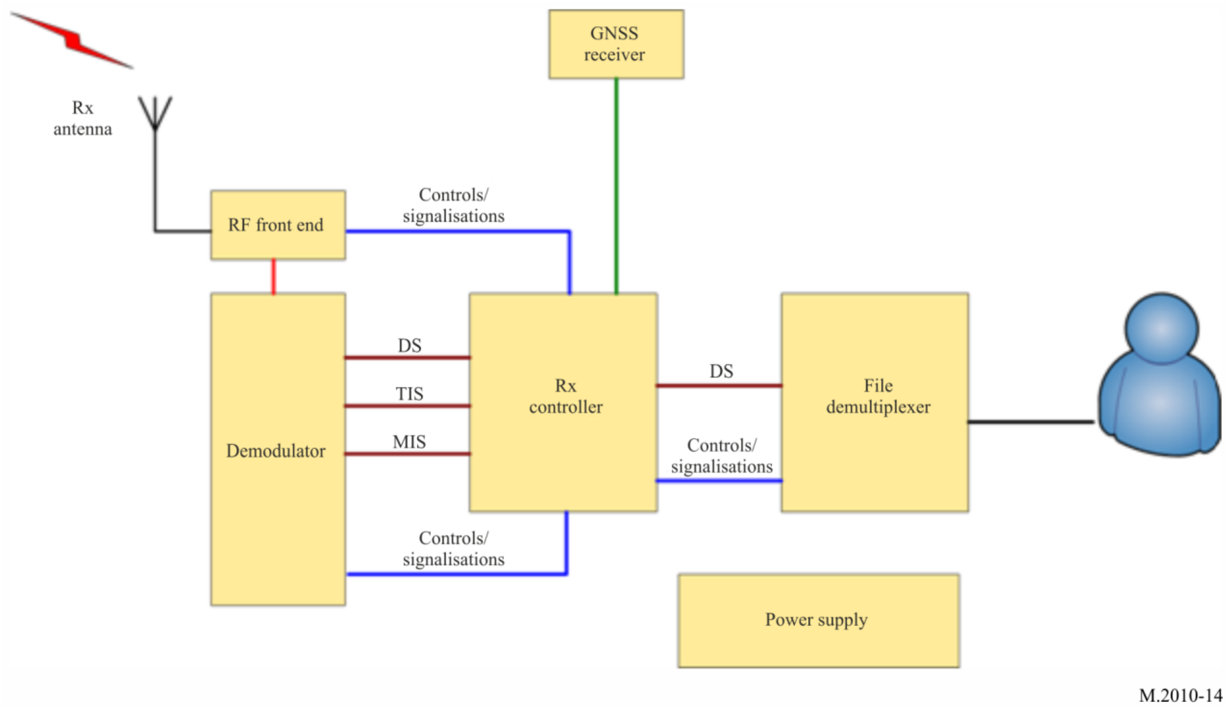
– Data interface;

– power supply.

The NAVDAT ship receiver can receive and decode the main MF channel and the main HF channel at the same time with 2 complete sub receivers. The first sub-receiver is constantly listening to the 500 kHz. The second sub-receiver is watching to the 4 226 kHz. In the case where no reception is found on the frequency 4 226 kHz the sub-receiver will scan all the 6 HF channels with a duration of 500 ms per channel. The design of this second receiver allow reception and decoding future potential regional or local transmitters using MF or HF channels.

FIGURE 16

NAVDAT receiver logical diagram



4.1.1 Reception antenna and global navigation satellite system antenna

The 500 kHz receiving antenna can be an H field antenna (recommended on a noisy ship) or an E field antenna. As an option, the ship's NAVDAT receiver can also receive NAVDAT HF channels. In this case, the receiving antenna system will have a band from 300 kHz to 25 MHz.

A GNSS antenna (or connection to the existing ship GNSS receiver) is also needed in order to obtain the ship position.

4.1.2 RF front end

This block includes the RF filter, RF amplifier and base band output.

High sensitivity and high dynamic range are necessary.

4.1.3 Demodulator

This stage demodulates the base band OFDM signal and recreates the data stream that holds the transmitted message files.

It implements:

– time/frequency synchronization;

– channel estimation;

– automatic modulation recovery;

– error correction.

The NAVDAT receiver should be able to detect the following modulation parameters automatically:

– 16 or 64-QAM;
– subcarriers scheme;
– type of error coding.

In addition to the DS, it reports the information filled in the TIS and MIS. Furthermore, it reports complementary information about the channel such as:

– estimated SNR;
– BER;
– MER.

4.1.4 File demultiplexer

The file demultiplexer:

– receives the message files from the controller;
– verifies that the message files are marked for its attention (type of broadcast mode);
– decrypts the message files if needed/able;
– makes the message files available for the terminal application that will use the message files;
– deletes the out-of-date message files.

Depending on the final application, the message file can be:

– stored on an onboard server accessible through the ship network;
– display on the receiver CDU directly;
– sent directly to the final application.

4.1.5 Controller

The controller:

– extracts the message files from the DS (merge packets into files);
– interprets the TIS and MIS and the other pieces of information given by the demodulator;
– collects the following information from the file demultiplexer:
  • total number of decoded message files;
  • number of available message files;
  • error event (e.g. decrypt errors).

4.1.6 Control and display unit

The receiver can provide a display and control unit, the function of this unit is:

– display the special information and by configuring the interface to be connected to a dedicated equipment application (e.g. e-navigation) and manage the licensed contents of the ship (e.g. ship identification, encryption);
– display and check the receiving parameters;
– display the message content according to the application classification of the message file.

This CDU may be a special application running on an external computer, and the receiver may be a black-box device.

4.1.7 Data interface

The receiver gets the data from external devices such as GNSS through the data interface. The controller classifies the message files according to their applications and provides the message files to the application devices through the data interface.

The equipment should provide a data interface that complies with the requirements of the IEC 61162 series. It is advisable to provide Ethernet and USB interfaces for high-speed transmission of files and also provide a printer interface.

4.1.8 Power supply

The main power supply must be adapted to the main power supply of the ship.

5 Minimum NAVDAT ship receiver performance specifications

These assumed ship receiver specifications are set out below with the objective to obtain minimum SNR for a good OFDM demodulation (4-QAM, 16-QAM or 64-QAM).

TABLE 6

NAVDAT ship receiver performance specifications

Parameters	Requirements
Frequency band	495 to 505 kHz
Adjacent channel protection	> 40 dB @ 5 kHz
Noise factor	< 20 dB
Usable sensitivity for BER (bit error rate) = 10^{-4} after error correction	< −100 dBm
Dynamic	> 80 dB
Minimal usable RF field (with adapted receiving antenna)	25 dB(μV/m)

Annex 4

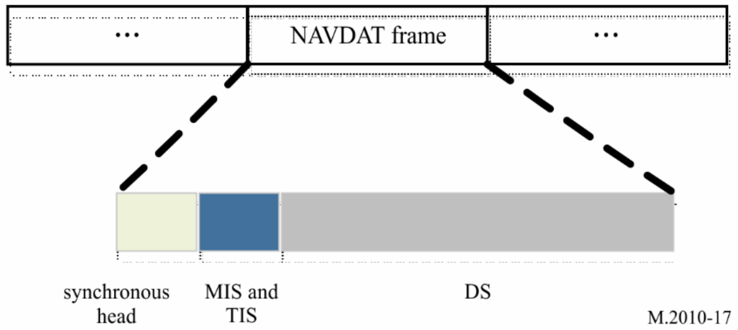
Transmission structure

1 Frame structure

NAVDAT frame structure contains synchronization head (the first symbol), MIS, TIS, and DS (data stream) shown as follow:

FIGURE 17

NAVDAT Frame structure



2 Synchronization head

Synchronization head is the first OFDM symbol of each frame for the receiver to synchronize and for the information on every subcarrier is shown in Table 7.

TABLE 7

Synchronization head sequence

Number of subcarriers	Synchronization head sequence
229	-1 1 1 1 1 1 1 -1 1 1 -1 -1 1 -1 1 1 1 1 1 -1 -1 1 -1 1 -1 -1 -1 1 1 1 1 -1 1 -1 -1 -1 - 1 1 1 -1 1 1 1 -1 -1 -1 1 1 1 -1 1 -1 -1 1 1 -1 1 1 -1 1 1 -1 -1 -1 1 -1 1 -1 -1 1 -1 -1 1 -1 1 1 -1 -1 -1 -1 1 -1 -1 1 -1 -1 -1 1 -1 1 1 1 -1 -1 1 -1 -1 1 1 -1 -1 -1 1 1 -1 1 -1 -1 1 -1 1 -1 1 1 0 1 -1 -1 -1 1 -1 -1 -1 -1 -1 1 -1 -1 -1 1 1 -1 -1 1 1 1 1 -1 -1 1 1 1 -1 1 -1 1 -1 1 1 1 -1 1 -1 1 -1 -1 -1 -1 -1 -1 1 1 -1 -1 -1 -1 -1 1 1 1 1 1 -1 1 -1 1 1 1 1 1 -1 1 1 1 1 -1 -1 -1 -1 1 1 1 -1 -1 1 1 1 -1 1 1 1 -1 1 1 -1 1 -1 1 1 -1 -1 1 1 -1 -1 1 - 1 -1 -1 -1 1 -1 1 -1 1 -1 1 -1 -1 1 1
115	1 -1 1 1 -1 -1 -1 1 -1 1 -1 -1 1 -1 -1 1 -1 1 1 -1 -1 -1 -1 1 -1 -1 1 -1 -1 -1 1 -1 1 1 1 1 -1 -1 1 -1 -1 1 1 -1 -1 -1 1 1 -1 1 -1 -1 1 -1 1 -1 1 1 0 1 -1 -1 -1 1 -1 -1 -1 -1 -1 1 - 1 -1 -1 1 1 -1 -1 1 1 1 1 -1 -1 1 1 -1 1 -1 1 -1 1 1 1 -1 1 -1 1 -1 -1 -1 -1 -1 -1 1 1 - 1 -1 -1 -1 -1 1 1 1 1 1 -1
69	1 -1 -1 1 -1 -1 -1 1 -1 1 1 1 -1 -1 1 -1 -1 1 1 -1 -1 -1 1 1 -1 1 -1 -1 1 -1 1 -1 1 1 0 1 -1 -1 -1 1 -1 -1 -1 -1 -1 1 -1 -1 -1 1 1 -1 -1 1 1 1 1 -1 -1 1 1 -1 1 -1 1 -1 1 1 1
23	1 -1 1 -1 -1 1 -1 1 -1 1 1 0 1 -1 -1 -1 1 -1 -1 -1 -1 -1 1

3 Modulation information stream

3.1 Structure

MIS is used to provide the information about channel spectrum occupancy as well as TIS and DS modulation:

– information of spectrum occupancy 2 bits;

– information of TIS modulation 1 bits;

– information of DS modulation 2 bits;

– padding bit 1 bit (=0);

– Cyclic redundancy check (CRC) 8 bits.

TABLE 8

Information of spectrum occupancy

Patterns of bits	Spectrum occupancy (kHz)
00	1
01	3
10	5
11	10

TABLE 9

Information of transmitter information stream modulation

Patterns of bit	Modulation
0	4-QAM
1	16-QAM

TABLE 10

Information of data stream modulation

Patterns of bits	Modulation
00	4-QAM
01	16-QAM
10	64-QAM

3.2 Encoding

The MIS is encoded by the RS(4,2) of GF(128) whose origin polynomial is $p(x) = x^7 + x^3 + 1$.

4 Transmitter information stream

4.1 Structure

TIS is used to provide the information about encoding of DS, transmitter, and time for the receiver:

– error encoding of DS 5 bits;

– identifier of the transmitter 30 bits;

– day and time 17 bits;

– reserved 23 bit (default: 0);

– CRC 8 bits.

TABLE 11

Encoding of data stream

Patterns of bits	Transmission mode		
	Spectrum occupancy (kHz)	Code rate	Modulation
00000	1	0.5	4-QAM
00001	1	0.75	4-QAM
00010	1	0.5	16-QAM
00011	1	0.75	16-QAM
00100	1	0.5	64-QAM
00101	1	0.75	64-QAM
01000	3	0.5	4-QAM
01001	3	0.75	4-QAM
01010	3	0.5	16-QAM
01011	3	0.75	16-QAM
01100	3	0.5	64-QAM
01101	3	0.75	64-QAM
10000	5	0.5	4-QAM
10001	5	0.75	4-QAM
10010	5	0.5	16-QAM
10011	5	0.75	16-QAM
10100	5	0.5	64-QAM
10101	5	0.75	64-QAM
11000	10	0.5	4-QAM
11001	10	0.75	4-QAM
11010	10	0.5	16-QAM
11011	10	0.75	16-QAM
11100	10	0.5	64-QAM
11101	10	0.75	64-QAM

TABLE 12

Identifier of the transmitter

Coding	ID of transmitter
$D_1D_2D_3D_4D_5D_6D_7D_8D_9D_{10}$	10 alpha numeric code

TABLE 13

Information of time

Parameter	Bit number	description
Hour of start time in UTC	5	hour
minute of start time in UTC	6	minute
Duration of broadcast	6	0-59 minutes

4.2 Encoding

The TIS is encoded by the RS (29,9) of GF(128) whose origin polynomial is $p(x) = x^7 + x^3 + 1$.

5 Data stream

5.1 Structure

Data stream generally consist of either text information or files of information. A generalized packet delivery allows the delivery of text information and files for various services in the same data stream. And services can be carried by a series of single packets.

The structure of a packet is as follows:

– Head 32 bits

– Data field n bytes

– CRC 16 bits.

The head is made up as follows:

– Data length 12 bits

– toggle bit 1 bit

– first flag 1 bit

– last flag 1 bit

– packet ID 10 bits

– padded packet indicator 1 bit

– reserved 6 bits.

Data length: This 12-bit indicates the length of a packet in bytes.

Toggle bit: This bit shall be maintained in the same state as long as packets from the same text message or file are being transmitted. When a packet from a different text message or file is sent for the first time, this bit shall be inverted with respect to its previous state. If a text message or file, which may consist of several packets, is repeated, then this bit shall remain unchanged.

First flat, Last flag: These flags are used to identify particular packets which form a succession of packets. The flags are assigned as follows:

TABLE 14

Coding of first flag and last flag

First flag	Last flag	The packet is
0	0	an intermediate packet
0	1	the last packet of a data unit
1	0	the first packet of a data unit
1	1	the one and only packet of a data unit

Packet ID: This 8-bit field indicates the packet ID of this packet.

Padded Packet Indicator: This 1-bit flag indicates whether the data field carries padding or not, as follows:

0: no padding is present: all data bytes in the data field are useful;

1: padding is present: the first two bytes give the number of useful data bytes in the data field.

Reserved: This 6-bit field is reserved for future use.

Data field: It contains the useful data intended for a particular service. It can be text information or file information.

CRC: This 16-bit CRC should be calculated on the header and the data field.

5.2 Encoding

NAVDAT data stream is encoded by low-density parity-check (LDPC), and different encoding parameters will be adopted in different modes (see Table 11). The following Table gives the LDPC parameters in 10 kHz mode.

TABLE 15

LDPC parameters of data stream

Modulation	Code rate	LDPC parameters
4-QAM	0.5	LDPC (2560,512)
4-QAM	0.75	LDPC (3840,5120)
16-QAM	0.5	LDPC (2560,5120) × 2
16-QAM	0.75	LDPC (3840,5120) × 2
64-QAM	0.5	LDPC (2560,5120) × 3
64-QAM	0.75	LDPC (3840,5120) × 3

6 Low-density parity-check codes

The LDPC code is a linear block code that can be uniquely defined by the parity check matrix H. Since the number of “1” in the parity check matrix H is much smaller than the number of “0”, it is called low density check code. The matrix H has double diagonal characteristic.

The check matrix H can be expressed as an exponential matrix shown as follow:

$$H = \begin{bmatrix} p_{0,0} & p_{0,1} & \cdots & p_{0,N-M} & 0 & \cdots & -1 & -1 & -1 \\ p_{1,0} & p_{1,1} & \cdots & \cdots & 0 & 0 & \cdots & -1 & -1 \\ \cdots & \cdots & \cdots & p_{i,N-M} & \cdots & \cdots & \cdots & \cdots & -1 \\ p_{M-2,0} & p_{M-2,1} & \cdots & \cdots & -1 & \cdots & 0 & 0 & -1 \\ p_{M-1,0} & p_{M-1,1} & \cdots & p_{M-1,N-M} & -1 & -1 & \cdots & 0 & 0 \end{bmatrix}$$

Each number represents an L x L matrix. "−1" denotes an all-zero matrix, 0 denotes a unit matrix, and p denotes a permutation matrix obtained by shifting the unit matrix to the right by p. The double diagonal matrix can be divided into two parts: information block and check block, namely: $H = [H_s\ H_p]$. And the vector of the encoded output symbols also can be divided into two parts, namely: $C = [S\ P]$. According to the check equation $[H_s\ H_p][S\ P]^T = 0$, the corresponding parity bit can be obtained.

The code length of LDPC in 10 kHz mode of NAVDAT is 5120, and the code rate is 1/2 and 3/4 respectively. The check matrix of the 1/2 code rate is:

$$\begin{bmatrix}
117 & -1 & -1 & -1 & 152 & -1 & -1 & -1 & 145 & -1 & -1 & 108 & -1 & 60 & -1 & 1 & 0 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\
-1 & 3 & -1 & -1 & -1 & 45 & -1 & 145 & -1 & -1 & 25 & -1 & 102 & -1 & -1 & -1 & 0 & 0 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\
-1 & -1 & 101 & -1 & 150 & -1 & -1 & -1 & -1 & 82 & 49 & -1 & 27 & -1 & 1 & -1 & -1 & 0 & 0 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\
-1 & -1 & -1 & 97 & -1 & 73 & -1 & 50 & -1 & -1 & -1 & 78 & -1 & 154 & -1 & -1 & -1 & -1 & 0 & 0 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\
123 & -1 & -1 & -1 & -1 & -1 & 53 & -1 & 101 & -1 & 43 & -1 & -1 & -1 & 118 & -1 & -1 & -1 & -1 & 0 & 0 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\
-1 & -1 & -1 & -1 & -1 & -1 & -1 & 123 & -1 & 93 & -1 & -1 & 103 & -1 & 157 & -1 & -1 & -1 & -1 & -1 & 0 & 0 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\
-1 & -1 & 120 & -1 & -1 & -1 & -1 & -1 & 10 & -1 & 155 & 31 & 7 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & 0 & 0 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\
-1 & -1 & -1 & -1 & -1 & -1 & -1 & 34 & -1 & 16 & 152 & -1 & -1 & -1 & 31 & 0 & -1 & -1 & -1 & -1 & -1 & -1 & 0 & 0 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\
-1 & -1 & -1 & 66 & -1 & -1 & 20 & -1 & 71 & -1 & -1 & -1 & 93 & 70 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & 0 & 0 & -1 & -1 & -1 & -1 & -1 & -1 \\
-1 & 44 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & 107 & -1 & 114 & -1 & 110 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & 0 & 0 & -1 & -1 & -1 & -1 & -1 \\
-1 & -1 & -1 & -1 & 112 & -1 & -1 & 21 & -1 & -1 & 132 & -1 & 3 & -1 & 104 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & 0 & 0 & -1 & -1 & -1 & -1 \\
65 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & 102 & 90 & -1 & 103 & -1 & 94 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & 0 & 0 & -1 & -1 & -1 \\
-1 & -1 & -1 & 0 & -1 & -1 & -1 & 7 & -1 & 101 & -1 & 74 & -1 & -1 & 55 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & 0 & 0 & -1 & -1 \\
-1 & 87 & -1 & -1 & -1 & -1 & 92 & -1 & 137 & -1 & -1 & -1 & 105 & 40 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & 0 & 0 & -1 \\
-1 & -1 & 141 & -1 & -1 & -1 & -1 & 38 & -1 & 80 & 0 & -1 & -1 & 0 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & 0 & 0 \\
-1 & -1 & -1 & -1 & -1 & 0 & -1 & -1 & 0 & -1 & -1 & 23 & -1 & -1 & 0 & 1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & 0
\end{bmatrix}$$

And the check matrix of the 3/4 code rate is:

$$\begin{bmatrix}
3 & -1 & -1 & -1 & 120 & -1 & 11 & -1 & 133 & -1 & -1 & 19 & 126 & -1 & -1 & -1 & 143 & 142 & -1 & -1 & 116 & 144 & -1 & 18 & 1 & 0 & -1 & -1 & -1 & -1 & -1 & -1 \\
-1 & 12 & 13 & -1 & -1 & 157 & -1 & 112 & -1 & -1 & 87 & -1 & -1 & -1 & 32 & -1 & -1 & -1 & 52 & 94 & 118 & -1 & 86 & -1 & -1 & 0 & 0 & -1 & -1 & -1 & -1 & -1 \\
76 & -1 & -1 & 75 & -1 & -1 & 74 & -1 & -1 & 28 & -1 & -1 & -1 & 94 & 138 & -1 & -1 & 13 & 73 & 119 & -1 & -1 & 4 & 90 & -1 & -1 & 0 & 0 & -1 & -1 & -1 & -1 \\
-1 & -1 & -1 & -1 & -1 & 14 & -1 & 61 & 51 & -1 & -1 & -1 & -1 & 117 & -1 & 93 & -1 & 103 & -1 & 2 & 5 & 60 & 153 & -1 & 0 & -1 & -1 & 0 & 0 & -1 & -1 & -1 \\
-1 & 23 & -1 & 106 & 7 & -1 & -1 & -1 & -1 & 143 & 16 & -1 & 101 & -1 & -1 & -1 & 126 & -1 & 122 & -1 & 111 & -1 & 29 & 120 & -1 & -1 & -1 & -1 & 0 & 0 & -1 & -1 \\
39 & -1 & 21 & -1 & -1 & 0 & -1 & -1 & 0 & -1 & -1 & 124 & -1 & -1 & 0 & -1 & 70 & -1 & 109 & -1 & 0 & 24 & -1 & 116 & -1 & -1 & -1 & -1 & -1 & 0 & 0 & -1 \\
-1 & 159 & -1 & -1 & 57 & -1 & -1 & 27 & -1 & 48 & -1 & 0 & 76 & -1 & -1 & 7 & -1 & 95 & -1 & 18 & -1 & 38 & -1 & 80 & -1 & -1 & -1 & -1 & -1 & -1 & 0 & 0 \\
-1 & -1 & 43 & 0 & -1 & -1 & 25 & -1 & -1 & -1 & 50 & -1 & -1 & 3 & -1 & 0 & -1 & 42 & 150 & 0 & -1 & 143 & 0 & -1 & 1 & -1 & -1 & -1 & -1 & -1 & -1 & 0
\end{bmatrix}$$

7 Cyclic redundancy check

For the bit error detection in DS, the 16-bit cyclic redundancy check should be calculated

at the end of each DS. The generator polynomial should be $G_{16}(x) = x^{16} + x^{12} + x^5 + 1$.

For MIS and TIS, the 8-bit cyclic redundancy check should be calculated and the generator polynomial should be $G_8(x) = x^8 + x^4 + x^3 + x^2 + 1$.

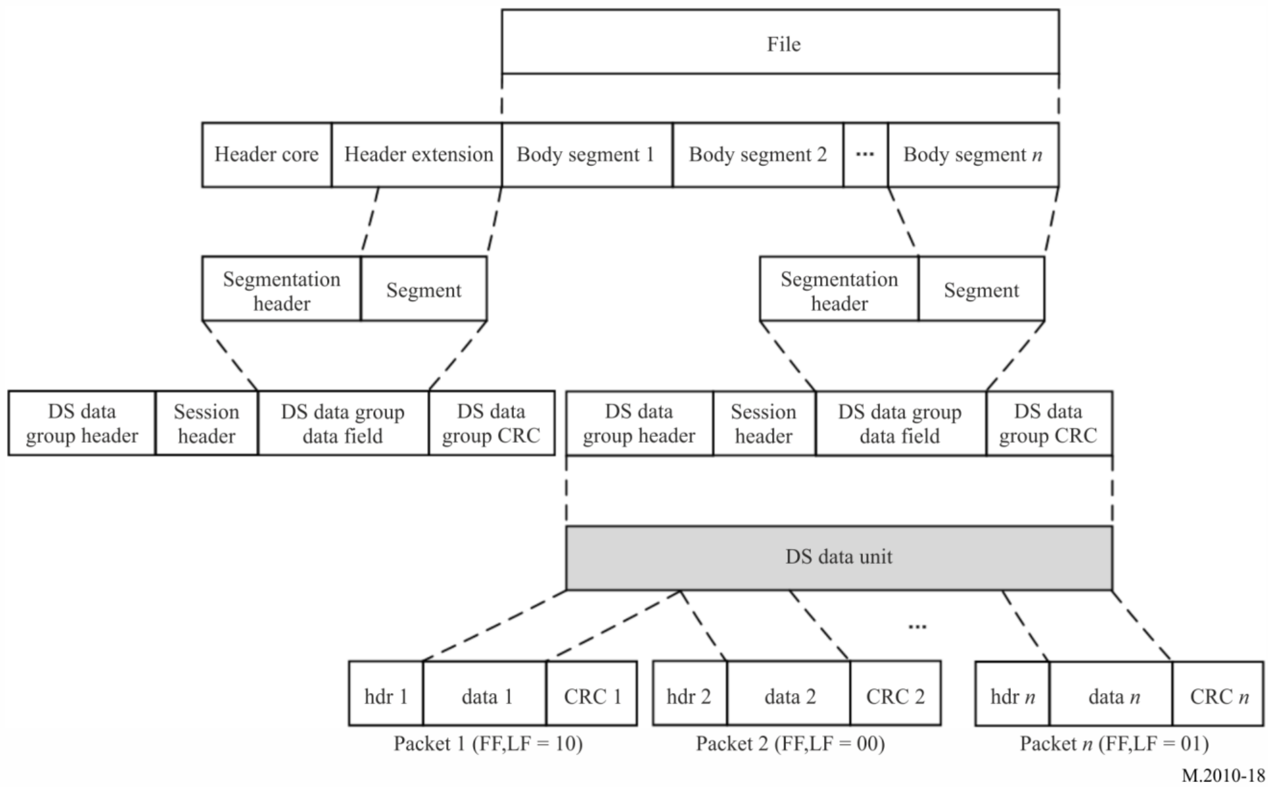
Annex 5

Message file structure

Figure 18 shows how a data group is built for a message file. In the first step, a header is created to describe the body (a message file). The header contains the file's management data. Afterwards, the header as well as the body are split into equally sized segments (only the last segment of each item may be smaller). A segment header is attached to a segment, and each segment is mapped into one data group. Then each data group with its header is mapped directly to a data unit. The data unit is split into packets for transportation. "FF" and "LF" represent the state of the "first flag" and "last flag" bits for each packet.

FIGURE 18

Message file structure



Annex 6

Single frequency network mode of Digital Radio Mondiale

1 Explanation of Digital Radio Mondiale

The international digital radio broadcast standard DRM is used for digital radio broadcasting at MF and HF. DRM is a proven technology that provides superior coverage, improves signal fidelity (through digital error correction coding), eliminates multi-path interference (including sky-wave interference) and thus extends coverage from sky-wave propagated signals. DRM broadcasts are implemented in both 16-QAM and 64-QAM modulation modes, depending on coverage requirements, transmitter location, power and antenna height.

1.1 Single frequency network operating mode

The system is capable of supporting what is called SFN operation. This is the case where a number of transmitters transmit on the same frequency, and at the same time, identical data signals. Generally these transmitters are arranged to have overlapping coverage areas, within which a radio will receive signals from more than one transmitter. Provided that these signals arrive within a time difference of less than the guard interval, they will provide positive signal reinforcement. Thus, the service coverage will be improved at that location compared to that obtained if there was only a single transmitter providing service to that location. By careful design, and using a number of transmitters in a SFN, a region or country may be completely covered using a single frequency, and in this application, a single time slot, thus drastically improving spectrum efficiency and release broadcast slots.